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Impact of Wind Farms on the Marine Atmospheric Boundary Layer

Patrick J.H. Volker[1], Alex Hall[2], Scott B. Capps[2], Hsin-Yuan Jerry Huang[2], Fengpeng Sun[2], Jake Badger[1] & Andrea Hahmann[1].

1. DTU Wind Energy, Roskilde, Denmark
2. Department of Atmospheric and Oceanic Sciences, UCLA, Los Angeles, CA, United States

Introduction

The presented work is part of a study sponsored by the California Institute of Energy and Environment, in which the impact of the aimed increasing contribution of clean alternative energy sources in the next 30 years will be investigated. Due to the huge wind energy potential along the Californian coast, we will focus on the environmental impacts of large offshore wind farms which become feasible, since offshore turbine technology has matured significantly in the last decade.

WF parametrization

We assume that the far wake can be described by a single length scale $\ell(x)$ and velocity scale $U_s(x)$. From the diffusion equation of the velocity deficit we can obtain a prognostic equation for the length scale

$$\partial_t \ell^2 = 2K_m,$$

where K_m represents the turbulence coefficient for momentum. This gives us

$$\ell^2 = \frac{2K_m}{U_0}x + \ell_0^2$$

Where ℓ_0 is the reference length scale and U_0 the background hub height velocity. Assuming an approximately Gaussian far wake shape leaves to

$$U(z) = U_0(z) - U_s f(z),$$

where U_s is the max. velocity deficit and $f = e^{z^2/(2\ell^2)}$. We obtain U_s from:

$$\frac{1}{2}C_t A_0 U_0^2 = W \int_0^{z_{\max}} U(U_0 - U)\,dz.$$

We obtain C_t from the thrust curve and the wake width W will be set to the grid size.

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- California Institute of Energy and Environment
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Model Setup

Our offshore wind farm consists of two hundred, current state of the art ($\sim 7MW$), wind turbines. The turbine hub height is at 125 m and the radius is 63 m. The wind farm size has been chosen via a linear extrapolation from current size wind farms up to the year 2020. The total wind farm capacity would roughly be enough to fully supply a city of the size of Oakland.

For this study we used the WRF mesoscale model V3.4. The exemplar wind farm has been placed to the north of the San Francisco bay, according to the high wind speed resources.

Since we are interested in the overall influence an annual simulation has been carried out. We have chosen the year 2009, since a variety of verification sources are available for that year. We used North American Regional Reanalysis data to provide the initial conditions and to force the outer domain every three hours. The horizontal resolution of the reanalysis data is 32km. Since we choose for a single nested set-up with 6 km and 2 km respectively, the domains had to be rather large. We applied nudging of the wind fields to the outer domain. For the Physics options, see Table (I).

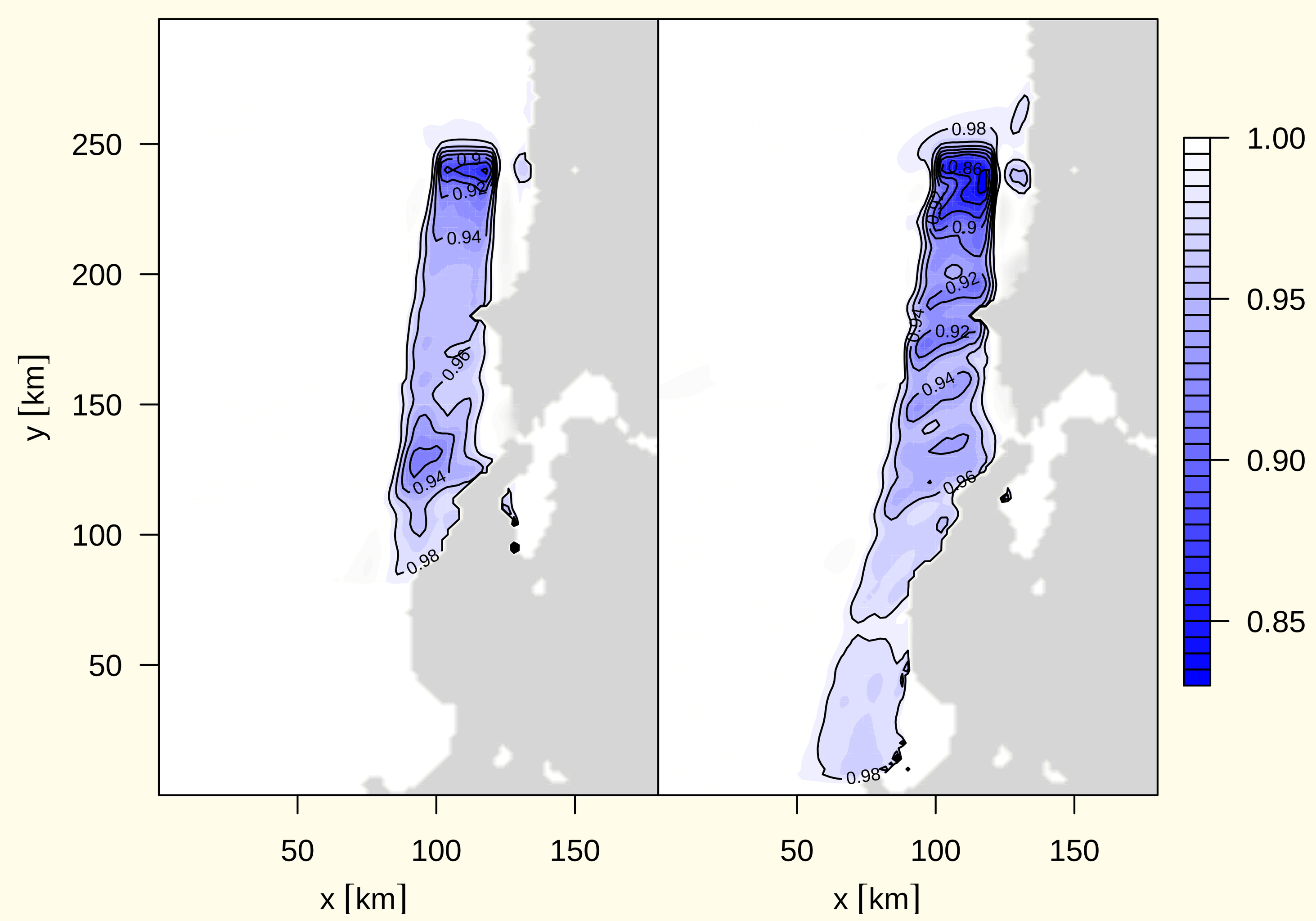
WRF simulation set up

Table (I)

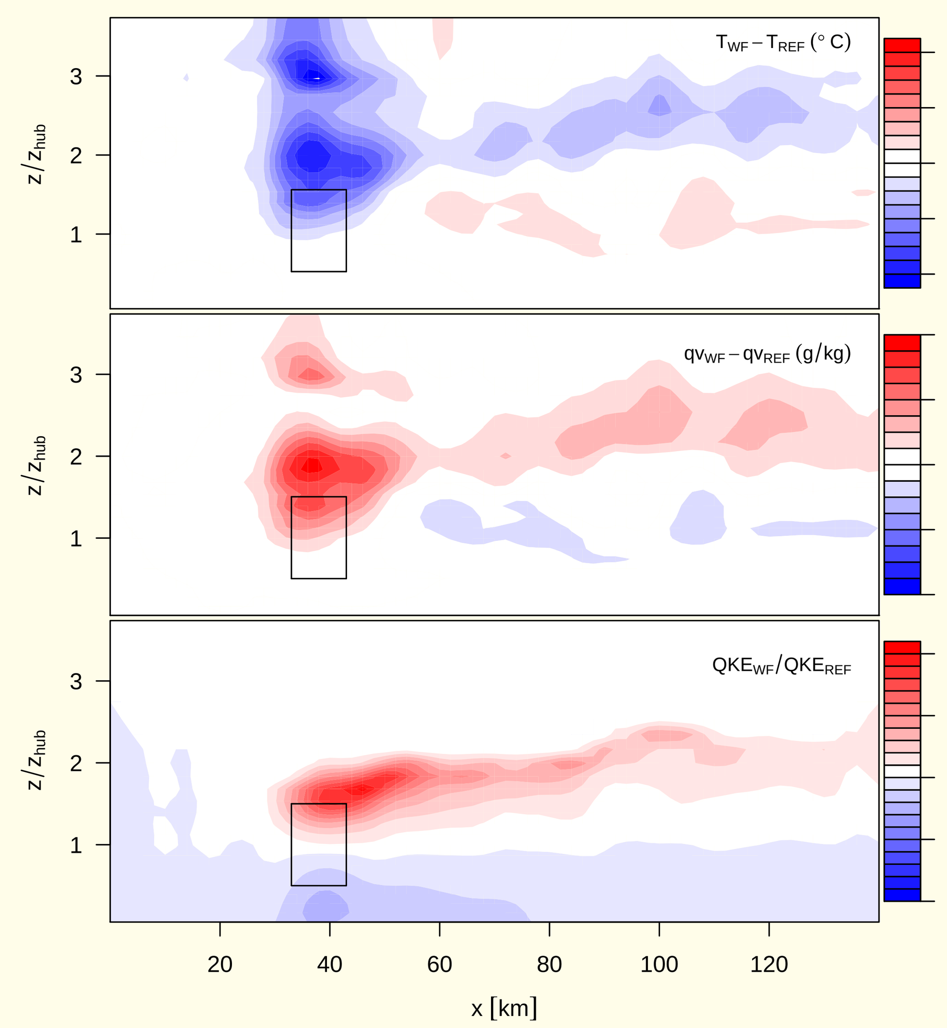
Domain	1	2
Resolution:	6 km	2 km
Vertical levels:	60	60
Micro-Physics:	Lin	Lin
Radiation, LW	RRTM	RRTM
Radiation, SW	Dudhia	Dudhia
Surface layer	MYNN	MYNN
PBL-Scheme	MYNN	MYNN
Convection	Kain-Fritsch	-

Preliminary Results

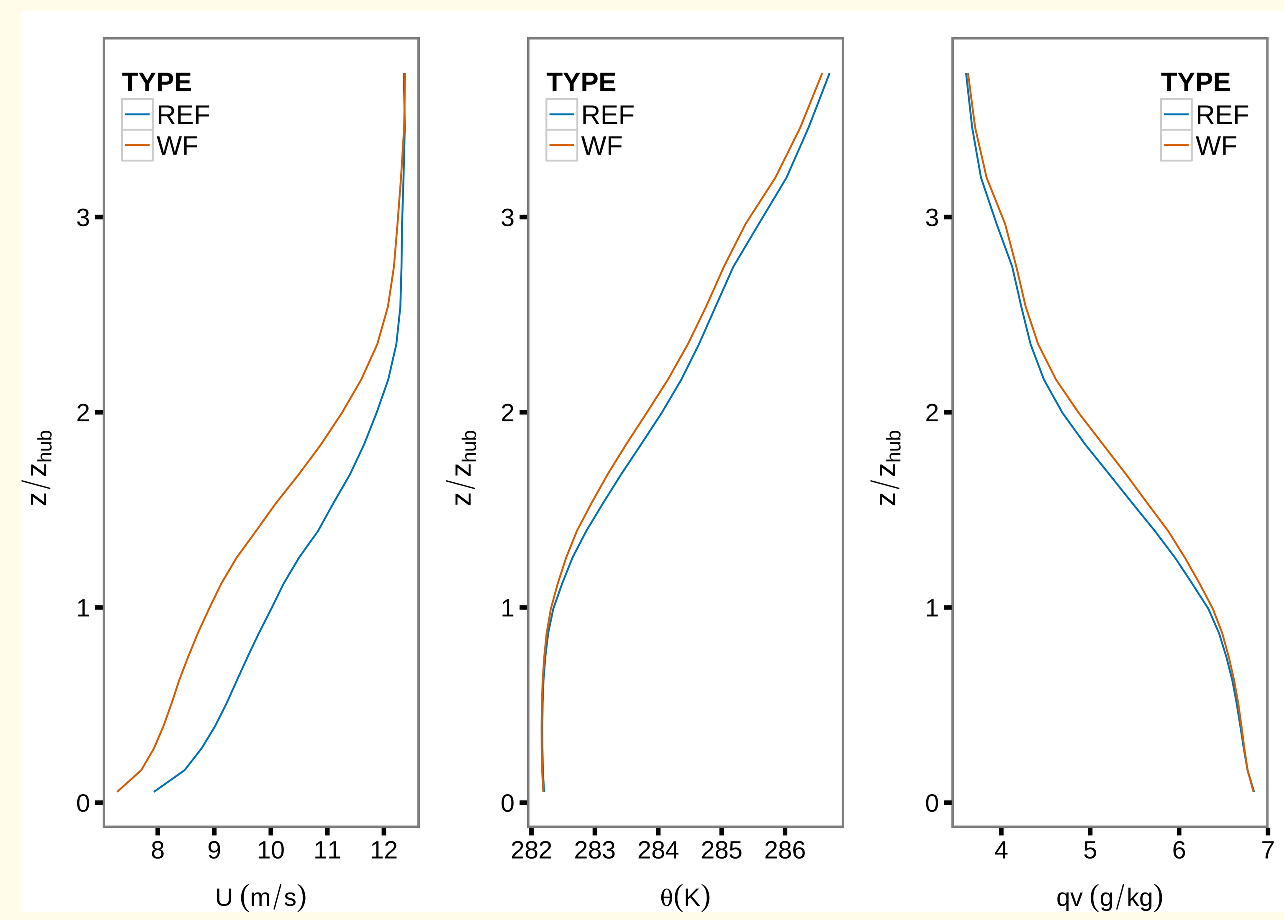
Below an example from January 1st at 21:00 UTC after a spin-up period of 21 hours is shown. We had at that particular moment steady conditions for 15 hours. The wind speed was 10 m s^{-1} $\pm$ 2 m s^{-1} and the wind direction 265° $\pm$ 10°.



Evolution of the velocity deficit U/U_{ref} at hub height over sea. Left January 1st at 15:00 UTC. Right January 1st at 21:00 UTC. The velocity deficit reaches a maximum of 19% directly after the wind farm and extends over 150 km with a deficit of 5%. The total extension up to 2 % is 250 km. Due to the reduced velocity the friction velocity $u_\star$ will also be lowered in the wake.



All above plots represent a 9-hour average from January 1st at 15:00 to January 2nd at 00:00 over the entire wind farm. Plots are cross sections of the wind farm. The rectangle represents the horizontal and vertical (tip to tip) extent of the turbine blades. An increase/decrease of QKE above/below hub height is found. This is due to the positive and negative shear regarding the reference run respectively. Also cold and moist air is transported upwardly above wind turbine hub height.



The plots represent a 9-hour average from January 1st at 15:00 to January 2nd at 00:00 of the vertical meteorological state over the wind farm. Due to the lateral velocity reduction inside the wind farm (left), stronger vertical mixing of thermal (middle) and moisture (right) is simulated.